

PRETREATMENT OF PALM OIL WASTE VIA TORREFACTION PROCESS

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ABSTRACT

Recently, the demand of energy increase as the population of the world keep increasing from years to another years. However the energy sources is not sufficient to survive with the demands. Malaysia is experiencing drastic growth in population and economy and requires exploring alternative energy sources to cope its population and commercial energy demand. Biomass as the fourth largest energy resource in the world is abundant in the country. Malaysia is one of the largest producer of palm oil industries have generated huge amount of biomass from palm oil. There are many types of biomass residue generated by the palm oil industry which includes fronds, trunks, empty fruit bunches (EFB), palm mesocarp fiber (PMF), and palm kernel shell (PKS). In general, oil forms about 10% of the whole oil palm trees while the other 90% remains as biomass. All those biomass are either utilized or discarded at the plantation or palm oil mills. In this study, three types of biomass were treated by using torrefaction process. Torrefaction process is strongly depended on thermal decomposition behaviour and composition of lignocellulosic constituents. Based on the torrefaction process, the moisture contents decreases of as temperature increases. The mass yield of EFB, PKS and PMF decreases as the temperature increase. For EFB, increasing of the temperature resulted in higher heating value. However, the heating value of PMF and PKS show the highest value at temperature 270°C. Palm mesocarp fiber and palm kernel shell exhibit excellent energy yield values which are higher than 90%. Empty fruit bunch, on the other hand, exhibited a rather poor energy yield of 70%.

ABSTRAK

Kebelakangan ini, permintaan daripada peningkatan tenaga sejajar dengan penduduk dunia yang meningkat dari tahun ke tahun. Walau bagaimanapun, sumber tenaga tidak mencukupi untuk terus memenuhi permintaan. Malaysia sedang mengalami peningkatan populasi serta ekonomi yang mendadak dan memerlukan penerokaan sumber tenaga alternatif untuk menampung penduduk dan permintaan tenaga komersial. Biojisim adalah sumber tenaga yang keempat terbesar di dunia dan boleh didapati dengan kuantiti yang banyak di negara ini. Malaysia adalah salah satu daripada pengeluar terbesar dalam industri minyak sawit dan telah menjana sejumlah besar biojisim daripada pokok kelapa sawit. Terdapat banyak jenis sisa biojisim yang dihasilkan oleh industri minyak sawit termasuk, pelepah, batang, tandan buah kosong (EFB), gentian mesokarpa sawit (PMF), dan tempurung isirong sawit (PKS). Umumnya, kira-kira 10% daripada keseluruhan pokok kelapa sawit menghasilkan minyak manakala 90% lagi akan kekal sebagai biojisim. Semua biojisim ini akan digunakan atau dibuang di kilang-kilang minyak sawit atau ladang. Dalam kajian ini, tiga jenis biojisim telah dirawat menggunakan proses *torrefaction*. Proses *torrefaction* amat bergantung kepada tingkah laku penguraian terma dan komposisi lignoselulosa. Berdasarkan proses *torrefaction* yang dijalankan, kadar kelembapan menurun apabila suhu meningkat. Hasil jisim bagi EFB, PKS dan PMF berkurangan sejajar dengan peningkatan suhu. Manakala untuk EFB, peningkatan suhu menyebabkan peningkatan yang lebih tinggi nilai pemanasan. Walau bagaimanapun, nilai pemanasan PMF dan PKS menunjukkan nilai yang paling tinggi pada suhu 270 °C. Gentian mesokarpa sawit dan tempurung isirong sawit mempamerkan nilai hasil tenaga yang sangat baik iaitu lebih tinggi daripada 90%. Namun, buah tandan kosong hanya menghasilkan jumlah tenaga yang agak rendah iaitu sebanyak 70 %.

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LIST OF ABBREVIATIONS

AWER	Association of Water and Energy Research Malaysia
CBBR	Center for Biofuel and Biochemical Research
EFB	Empty fruit bunch
FFB	Fresh fruit bunch
LCSB	LKPP Corporation Sdn Bhd
LKPP	Lembaga Kemajuan Perusahaan Pertanian
MTOE	Metric of oil equivalent
PKC	Palm kernel cake
PKS	Palm kernel shell
PMF	Palm mesocarp fiber
UNITEN	Universiti Tenaga Nasional
UTP	Universiti Teknologi PETRONAS

1 INTRODUCTION

1.1 Motivation and problem statement

Energy is one of the most vital elements that required in our daily life which is used for transportation, telecommunication and industrial activities that influence the economic growth. Today, energy crisis turn out to be a serious threat towards sustainability for developing countries since their energy demand is growing more rapidly than developed countries. In Malaysia, the electricity energy sector is forecasted growth, the demand is expected to escalate from 91,539GWh in year 2007 to 108,732GWh in year 2011 (VGR, et al., 2010). By year 2020, the energy demand in Malaysia is projected to reach 116 MTOE based on an annual growth rate of 8.1% (Shafie, et al., 2011). The Malaysian energy sector is still heavily dependent on non-renewable fuel such as fossil fuels and natural gas as a source of energy. However, those conventional fuels will not able to sustain for another 100 years and limited (Mekhilef, et al., 2011). Those non-renewable fuels are finite and gradually depleting and also contribute to the emission of greenhouse gases (Jamaludin, 2010). Thus, we need to find another alternative in substituting the non-renewable energy to the renewable and other alternative energy. Therefore, biomass energy is the preeminent substitute to petroleum-derived energy and the most suitable as a backup for sustainable energy development. By the year 2050, biomass is expected to become the most prominent renewable energy source with a four-fold increase to 23% of the total world primary energy (Umar, et al., 2014). Malaysia, is a tropical country that experiences hot and wet weather throughout the year. Those climate has encourages the growth of the oil palm and presently Malaysia was occupied with million hectares of land with palm oil plantation generating huge quantities of biomass (Pei, et al., 2012). It clearly shows that biomass from palm oil industries will be a very promising alternative as a source of raw materials (Shuit, et al., 2009). The abundance availability of palm oil waste in country since Malaysia is one of the largest producers of palm oil industry will lead to an average of 53 million tonnes of residues each year and it is projected to rise to 100 million dry tonnes of palm oil biomass by the year 2020 (Umar, et al., 2014).

Oil palm, or also known as *Elaeis guineensis* is a perennial tree crop (Shuit, et al., 2009)(Yusoff, 2004), which is cultivated extensively in the humid tropical land. There are many types of biomass residues generated by the palm oil industry which includes fronds, trunks, empty fruit bunches (EFB), palm mesocarp fiber (PMF), and palm kernel shell (PKS) (Wei & Po, 2010). In general, oil forms about 10% of the whole oil palm trees while the other 90% remains as biomass. All those biomass are either utilized or discarded at the plantation or palm oil mills. Biomass has the highest potential to contribute to energy needs and replace the existing conventional fuel. Since Malaysia is the largest producer of palm oil industry, so the main raw materials used in this study were comes from palm oil industry. Besides of the abundance availability of sources, it also eco-friendly and can reduce the effect of global warming. Burning of palm oil biomass instead of fossil fuels as an energy source, it will displace a certain amount of carbon that would have been released to the environment (Shuit, et al., 2009). Reduction in carbon emission to the environment is crucial to prevent further global warming. However, biomass has its own limitation properties that need to overcome in order to utilize biomass efficiently. To develop energy from biomass, various conversion technologies such as physical, chemical, thermal, and biological methods have been utilized. The most commonly technique used is thermal conversion like direct combustion, pyrolysis, gasification and liquefaction (Zhang, et al., 2010). But, many problems occur in order to utilize raw biomass because of its characteristics. From the previous studies, torrefaction process is the most suitable pretreatment process that compatible with the biomass characteristic itself. Energy density of pretreated biomass could be increased by 8-36% depending on torrefaction conditions (Uemura, et al., 2011). Torrefaction is a promising technique to improve the performance of biomass for energy utilization. As can be seen, most studies only focusing on several types of biomass and parameter such as energy yield or mass yield based on difference temperature. Hence, more research is required to study more about torrefaction process using different biomass and different parameters.

1.2 Objectives

The objectives of this work are:

- To study about pretreatment of palm oil waste via torrefaction process.

- To study the influence of torrefaction process on physical and chemical properties of biomass.

1.3 Scope of this research

The following are the scope of this research:

- i) Construction of experimental rig for palm oil waste; empty fruit bunch, palm mesocarp fiber and palm kernel shell performance analysis
- ii) Experimental analysis of torrefied biomass based on mass and energy yield, moisture content using temperature dependence parameter.

2 LITERATURE REVIEW

2.1 Overview

Torrefaction, a thermochemical conversion process, has gained global attention as a viable pretreatment technology for biomass feedstock in gasification and co-combustion processes (Olumuyiwa, et al., 2014). Torrefaction process is a thermal pre-treatment process at temperature ranged of 200 °C to 300 °C (Aziz, et al., 2012) (Chen & Kuo, 2011) (Prins, et al., 2006) and resulting of numerous improvement on torrefied biomass such as reduce the moisture content, increase the energy density, and increase the heating value (Uemura, et al., 2012) . Therefore, the purpose of this project is to study about the influence of torrefaction process on physical and chemical properties of biomass. Biomass, is biological material derived from living organisms such as wood and herbaceous material (Tumuluru, et al., 2011). It is used as renewable energy source to generate electricity or to produce heat. However, several weakness of biomass have limited its wider application in energy generation. These include low heating value, high moisture content, low energy density and low grindability properties (Jaafar & Ahmad, 2011). It, therefore often needs to pre-treat to improve the weakness of the biomass. Torrefaction promises to deliver a solid biofuel which has superior characteristics such as increase the heating value and energy density, lower the moisture content and also in terms of handling, milling and transport. This has potential to vastly improve the competitiveness of biomass as renewable energy carrier (Batidzirai , et al., 2013).

2.2 Introduction

Energy is a property of objects that cannot be create or destroy but can be transferred among them via fundamental interaction. It is one of the furthermost elements that essential in our daily life. Energy is crucial to all aspects of development from powering manufacturing and modernization of agricultural sectors to providing electricity to run schools and health facilities, yet the impact of its production, distribution and use grows more severe with every decade (Mohamed & Lee, 2004). Most of daily routine are consume energy such as transportation, telecommunication as well as industrial activities and those activities influence the growth of economy. In Malaysia, more than 50% of domestic consumers use less than 200 kilowatt-hour (kWh) of electricity

monthly. However, the percentage of domestic consumers that use less than 200 kWh electricity monthly steadily decrease since the electric product become cheaper. Increase the electricity consumption means increasing the living cost and at the same time will impact the environment.

Nowadays, energy crisis turn out to be a serious threat towards sustainability for developing countries since their energy demand is growing extra speedily than developed countries. In Malaysia, electric sector is depending on fossil fuels. Regrettably, there are a number of serious problems with burning these fuels to provide energy. It will cause significant damage to the natural and built environments as well as human health. Burning fossil fuels releases a number of chemical into air such as carbon dioxide, nitrogen dioxide, heavy metals, sulfur dioxide and volatile organic compounds. Those chemicals released through burning of fossil fuels can lead to acid rain, which can cause damage to plants and buildings. Besides that, changing the proportion of carbon dioxide in the atmosphere can lead to changes in the climate which could affect weather patterns and sea level too. Furthermore, burning of fossil fuels will cause health problem. Heavy metals that are released into air as a result from combustion of fuels can lead to higher rates of cancer and increased risk of respiratory illnesses in the surrounding area. And, the most serious problem of fossil fuels is that they are non-renewable (RP, 2007). Thus, a drastic step should be taken in order to overcome the problem of using fossil fuels as conventional sources. Therefore, many research have been carried out to find an alternative to substitute the conventional source. As a result, biomass energy is the preeminent substitute to petroleum-derived energy and the most suitable as a backup for sustainable energy development.

2.3 Biomass and its characteristics

Biomass is an organic material that derived from botanical or biological. It is a non-fossilized fuel source that is biodegradable. It also sustainable and renewable energy sources and has highest potential to contribute to energy needs and replace the existing conventional fuel since it is abundant, clean and carbon dioxide neutral. It is the third largest primary energy sources after coal and oil (Zhang, et al., 2010). Biomass can be divided into two main class which are virgin biomass and waste biomass. Virgin biomass comes from terrestrial or aquatic source. Meanwhile, for waste biomass comes

from industrial waste, municipal waste, agricultural solid waste and forestry waste. Table 2-1 shows the biomass classification and their example.

Table 2-1: Biomass Classification (Tumuluru, et al., 2011)

Virgin Biomass	Waste Biomass
<ul style="list-style-type: none"> • Terrestrial • Aquatic 	<ul style="list-style-type: none"> • Municipal waste • Agricultural solid waste • Forestry residue • Industrial waste

Biomass is made up of cellulose, hemicellulose, lignin, extractives and inorganics (ash) with different physical and chemical properties due to its diverse origin and species. Cellulose with a molecular weight of about 100,000 is a polymer with linear chains of glucopyranose units linked to each other by its 1,4 carbon atoms in the β -configuration. Hemicellulose, the second major constituent with lower molecular weight, is a mixture of various polymerized monosaccharides such as glucose, mannose, galactose, xylose, arabinose, methyl glucuronic and galacturonic acid residue. A highly branched polymer attached with polysaccharides, lignin, is composed of phenyl propane based monomeric units linked together by several types of ether linkages and also various kinds of carbon-carbon bonds (Kong, et al., 2014). Not only that, biomass also have their own characteristics that cause the several problem in order to generate energy from it. Consequently, the biomass need to pre-treat before further process to generate energy is taken. There are many problem regarding the biomass such as higher energy consumption during collection, low energy density, low calorific value, and high moisture content. Various conversion technologies have been explore in order to utilize the raw biomass caused by its characteristics. The most common technique is thermal conversion, the technique that based on the temperature as the parameter. Example of thermal conversion applied are direct combustion, pyrolysis, gasification and liquefaction (Zhang, et al., 2010). However, a pre-treatment method called torrefaction is found to be effective process to overcome the limitation properties of raw biomass.

Torrefaction is a promising pretreatment technology with potential to make a major contribution to the commodification of biomass. Torrefaction is a process of thermal

pretreatment to pretreat biomass that maintained by an operating temperature ranging from 200°C to 300°C (Jaafar & Ahmad, 2011). It is carried out under atmospheric pressure, in the absence of oxygen and in the flow of nitrogen gas. This process strongly depended on the decomposition temperature of the lignocellulosic constituents in biomass. There are many advantages of torrefaction to the raw biomass. Table 2-2 show the biomass characteristics and improvements through torrefaction pretreatment.

Table 2-2: Biomass characteristic and improvement through torrefaction pretreatment (Batidzirai , et al., 2013)

<i>Biomass Characteristic</i>	<i>Improvement through torrefaction pretreatment</i>
<i>Low heating value (due to low fixed carbon content of about 45% and relatively high moisture content, typically about 50%)</i>	Increase fixed carbon; the fixed carbon content of torrefied biomass is high (25-40% depending on the reactions conditions). Combustion properties: torrefied biomass burns longer due to larger percentage of fixed carbon
<i>Lower energy density than fossil fuels (2-4 GJ/m³)</i>	Densification: Torrefied and pelletised biomass (TOPs) has high energy density of 18-20 GJ/m ³ . It contains 40-80% of the original mass while retaining 80-96% of the original energy of the dry biomass.
<i>Hydrophilic and hygroscopic (absorbs moisture during storage and transportation)</i>	Hydrophobicity: torrefied biomass becomes hydrophobic. The equilibrium moisture content of torrefied biomass is very low (from 1 to 3%), but depends on severity of torrefaction
<i>Heterogeneous characteristics (wide range of shapes, sizes and types) and quality</i>	Torrefaction produces a solid uniform product, as volatiles and moisture are eliminated. On grinding the particle size distribution, sphericity and particle surface areas become similar to coal. It also results in improved chemical composition making it more suitable for fuel applications.
<i>Low combustion efficiency</i>	Reduced oxygen: torrefaction reduces the O/C ratio and this makes a biomass better suited for gasification. Torrefied biomass also produces less smoke during combustion since smoke causing

	volatiles are driven off during torrefaction.
<i>Tough and fibrous, difficult to pulverize</i>	Improve grindability: torrefied biomass requires less energy to grind compared to raw biomass.
<i>Biodegradable: due to moisture and environmental stress</i>	Stable: torrefied biomass has very low moisture and can therefore be transported and stored for long periods without any biological degradation.
<i>Small quantity scattered over many sources locations and seasonal availability</i>	Biomass can be torrefied and pelletised in decentralised locations and stored for long period without an impact of its quality. It also improve the economics of transportation and handling biomass.

2.4 Palm Oil Waste as Biomass

Palm tree usually have a vertical trunk and feathery leaves known as palm frond. Every year around 20-40 new leaves are grown. Bunches of palm fruit develop between trunk and base of the new fronds. After 5-6 years of plantation, the first crop of fresh fruit can be harvested and each tree can provide palm fruit for 25-30 years. Each fruit has a spherical shape and black color before turning to orange-red when ripe (Hosseine & Wahid, 2014). Normally, about 10% of the whole palm oil trees will produces oil while the other 90% remains as biomass. Fresh fruit bunch contains only 21% palm oil, while the rest are 14-15% fiber, 6-7% palm kernel, 6-7% shell and 23% empty fruit bunch which left as biomass (Aziz, et al., 2012; Fauzianto, 2013). Figure 2-1 illustrates the typical palm tree and fresh fruit bunch (FFB).

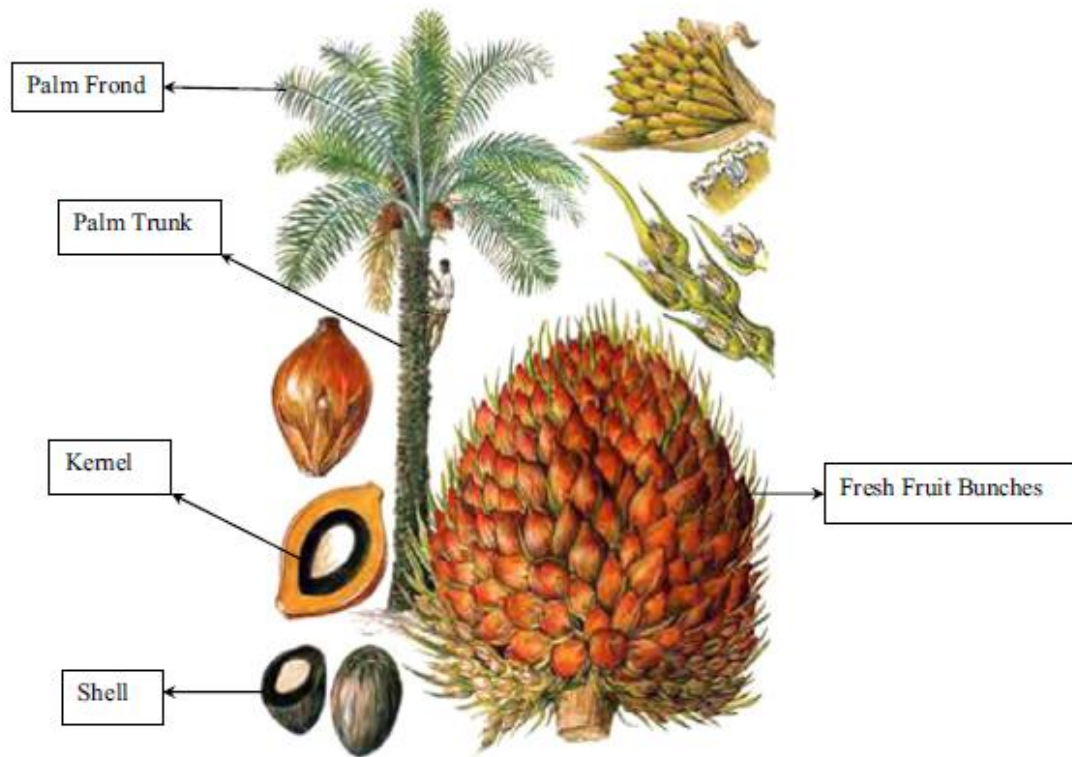


Figure 2-1: Typical palm tree and FFB (Hosseine & Wahid, 2014)

In recent decades, Malaysian government has introduced biomass as the fifth fuel resource after petroleum, gas, coal and hydro (Yaakob, et al., 2011). The most important biomass resources in Malaysia are agricultural waste, effluent sludge, domestic waste as well as wood chips. However, due to specific weather circumstances, palm oil biomass has been developed in huge quantities in Malaysia. Since the abundance of palm oil biomass, it seem to have a great potential to be utilized in different industries. Some solid residues and leftovers like EFB, PMF and PKS from palm oil fruit remains in the harvesting process and also palm oil mills. Therefore, the palm tree plantation in Malaysia are continuously increasing due to Malaysia government strategies for palm-oil based biodiesel production. Figure 2-2 demonstrates the types of different by-products generated annually from palm oil industry as palm biomass in Malaysia.



Figure 2-2: Summary of biomass by-product generation in palm oil industries in Malaysia.

As illustrated in Figure 2-2, a lot of biomass by-product has been generated in palm oil industries in Malaysia. Therefore, abundant waste biomasses are turned into renewable energy or value added product. Table 2-3 shows the types of renewable energy in Malaysia and its energy value. From the table shown, palm oil biomass is the second largest that contribute in energy after forestry residues.

Table 2-3: Type of renewable energy source in Malaysia and energy value (Sumathi, et al., 2008)

Renewable energy source	Energy value in RM million
-------------------------	----------------------------

(annual)	
Forest residues	11,984
Oil palm biomass	6379
Solar thermal	3023
Mill residues	836
Hydro	506
Solar	378
Municipal waste	190
Rice husk	77
Landfill gas	4

The production of palm biomass was approximately 87 Mt in 2010, although this value excludes oil palm fronds and trunks, which would further increase the amount of biomass produced by the palm oil industry. The potential energy that can be generated by palm oil biomass is shown in Table 2-4. Those amount of energy may be wasted due to inefficient utilisation of the palm oil biomass. Recently, the government of Malaysia has set target to increase its biomass power generation capacity to 800MW by 2020, and 500MW is to be generated from palm oil biomass.

Table 2-4: Amount of biomass available as 2010 (Qin Ng, et al., 2012)

Biomass available from palm oil industry	Quantity (Mt/y)	Potential energy (MTOE/y)^a
Empty Fruit Bunch	21.27	9.55
Mesocarp Fiber	10.80	4.92
Palm Kernel Shell	4.98	2.39

Palm Oil Mill Effluent	49.85	20.23
Total	86.90	37.09

^a 1 Mt of oil equivalent (MTOE) = 41868 MJ

2.5 Type of Palm Oil Biomass

Many type of biomass that generated from palm oil industries such as empty fruit bunch (EFB) , palm kernel shell (PKS), palm kernel cake (PKC), palm mesocarp fiber (PMF) , fronds and trunks. Yet, this study only focus on three types of biomass which are EFB, PKS and PMF.

2.5.1 Empty Fruit Bunch (EFB)

EFB is formed from fresh palm oil fruit bunch (FFB) that went through steam heating and put under threshing process which separate palm fruit from its bunch. Figure 2-3 illustrated the real picture of EFB taken from the palm oil mill.



Figure 2-3: Empty Fruit Bunch

Each biomass contains its own characteristics and application. Table 2-5 how the physical properties of EFB such as moisture content, calorific value and elementary and ash analysis. In addition, the chemical of composition of EFB has been listed on Table 2-6.

Table 2-5: Physical properties of EFB (Uemura, et al., 2011)

Moisture content	Calorific value		Elementary and ash analysis						Form
	(MJ/kg)		C	H	N	S	O	Ash	
	Wet (HHV)	Dry (HHV)							
65	-	19.1	48.8	6.30	0.20	0.20	36.7	7.3	Fiber of 1 mm in diameter

Table 2-6: Chemical composition of EFB (Aziz, et al., 2012)

Component	Hemicellulose	Cellulose	Lignin
EFB (wt %)	35.3	38.3	22.1

As mentioned before, each type of biomass have their own physical properties. Different properties will contribute to different type of application. For EFB, it has own application. There are several application of EFB in various industries (Sumathi, et al., 2008):

1. Convert into paper-making pulp. The paper can be used as cigarette paper or bond paper for writing.
2. Used as soil conditioner in estate and plantation. It will incinerated to obtain oil palm ash (OPA) that can be used as a source of fertilizers due to its high potassium.
3. Manufacture medium density fiber board (MDF) and blackboard.
4. Used to produce glucose and xylose
5. Used as a feedstock for second generation ethanol to produce bio-oil and bio-ethanol.

2.5.2 Palm Mesocarp Fiber

An elongated cellulose that generated at the nut/fiber separator is known as palm mesocarp fiber. PMF is one of the biomass that used in this study. The physical properties and chemical composition of the PMF is shown in Table 2-7 and 2-8, respectively. Figure 2-4 show the image of PMF that generate from palm oil industries.



Figure 2-4: Palm mesocarp fiber

Table 2-7: Physical properties of PMF (Uemura, et al., 2011)

Table 2-7. Physical properties of PMF (Sekar, et al., 2011)									
Moisture content	Calorific value		Elementary and ash analysis						Form
	(MJ/kg)								
	Wet (HHV)	Dry (HHV)	C	H	N	S	O	Ash	
42	-	18.8	47.2	6.00	0.30	0.20	36.7	8.4	Fiber of 1 mm in diameter

Table 2-8: Chemical compositions of PMF (Aziz, et al., 2012)

Component	Hemicellulose	Cellulose	Lignin
PMF (wt %)	31.8	34.5	25.7

PMF also have its own application that can be applied in many types of industries such as agriculture as soil conditioner. There are a lots of application of PMF like (Sumathi, et al., 2008):

1. Used as a boiler fuels to generate steam for mill consumption.
2. Used as soil conditioner in estate and plantation. It will incinerated to obtain oil palm ash (OPA) that can be used as a source of fertilizers due to its high potassium.

3. Manufacture medium density fiber board (MDF) and blackboard.
4. Can be converted into value added products such as oil palm activated carbon.
This palm oil activated carbon has been used to treat air toxics such as carbon monoxide (CO) and SO_x

2.5.3 Palm Kernel Shell

PKS is a crushed nuts of palm oil fruits. It is a by-product of palm oil production. It is carbonaceous solids that contain high volume percentage of carbon element and can be converted as a heat energy source. PKS also known as “Virgin Biomass”, free of chemical treatment, metallic plastics and not obvious degraded, not sticky and manageable in normal loading/discharging (Nordic , 2011). Figure 6 shown the picture of palm kernel shell.



Figure 2-5: Palm Kernel Shell

Table 2-9 shows the physical properties of PKS and the chemical composition of PKS is shown in Table 2-10.

Table 2-9: Physical Properties of PKS (Jaafar & Ahmad, 2011) (Uemura, et al., 2011)

Moisture content	Calorific value (MJ/kg)		Elementary and ash analysis						Form
	Wet (HHV)	Dry (HHV)	C	H	N	S	O	Ash	
2.88	-	18.81	46.5	5.85	0.89	0.20	42.3	4.3	

Table 2-10: Chemical composition of PKS (Aziz, et al., 2012)

Component	Hemicellulose	Cellulose	Lignin
PKS (wt %)	22.7	20.8	50.7

PKS has less application compare to PMF and EFB because of its own characteristics and properties. However, PKS can be used as a boiler fuels to generate steam for mill consumption and can be converted into value added products such oil palm activated carbon. This palm oil activated carbon has been used to treat air toxics such as carbon monoxide (CO) and SO_x (Sumathi, et al., 2008).

2.6 Torrefaction process

Torrefaction is a process used to produce high-grade solid biofuels from various streams of streams of woody biomass or agro residues. The end product is stable, homogenous, high quality biofuel with far greater energy density and calorific value than the original feedstock, providing significant benefits in logistics, handling and storage, as well as opening up a wide range of potential uses.

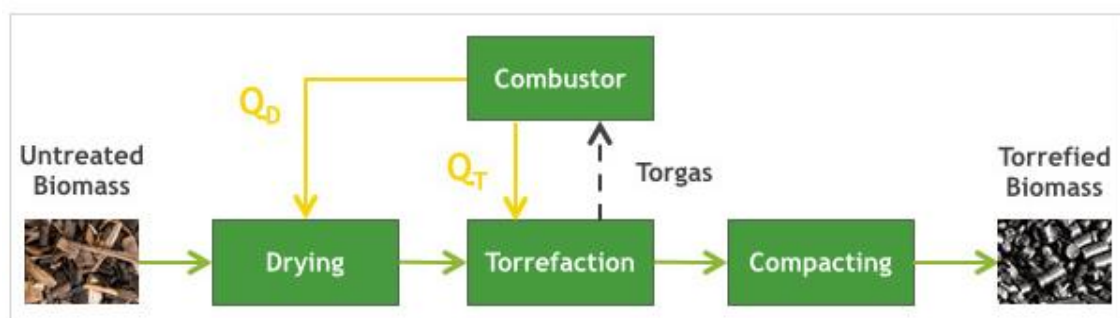


Figure 2-6: Basic Torrefaction Principle

Torrefaction is a thermal process that involves heating the biomass to the temperatures between 200 to 300 °C in an inert atmosphere. When biomass is heated at such temperatures, the moisture evaporated and various low-calorific components contained in the biomass are driven out. During this process the hemicellulose in the biomass decomposes which transforms the biomass from a fibrous material into a product with excellent fuel characteristics.

As a result of torrefaction of biomass, high grade biofuel is produced which can be used as a replacement of coal or fossil fuels in electricity and heat production. It also can be used as fuel for gasification process in the production of high value bio-based fuels and chemicals.

2.7 Torrefaction in Malaysia

In recent decades, Malaysian government has introduced biomass as the fifth fuel resource after petroleum, gas, coal and hydro. However, before biomass can be used as the alternative resources, it must be treated because of its characteristics. There are several research that have been carried out in Malaysia about torrefaction process. One of them is torrefaction in the presence of oxygen and carbon dioxide (Saadon, et al., 2014). The research was carried out by Center for Biofuel and Biochemical Research (CBBR), Universiti Teknologi Petronas (UTP), is to study the behaviour of torrefaction diverged when the process was carried out in the presence of oxygen and carbon dioxide. The chosen biomass is oil palm kernel shell due to its abundance in Malaysia.

Other than that, another researcher from Universiti Tenaga Nasional (UNITEN), has developed a bench scale biomass torrefier to produce samples of torrefied biomass to be used for further fuel characterization such as calorific value and ultimate analysis (Mohd Jaafar, et al., 2013). Previous work on torrefaction on Malaysian biomass had been done using thermogravimetric analyser (TGA) or tube furnace apparatus as the torrefier. Those apparatus can only torrefy small amount of biomass, a maximum of 5g, at a time. So, only a small amount will produce and insufficient sample size for further characterization studies. Hence, by developing a bench scale torrefier, it could handle a larger biomass sample for characterization studies.